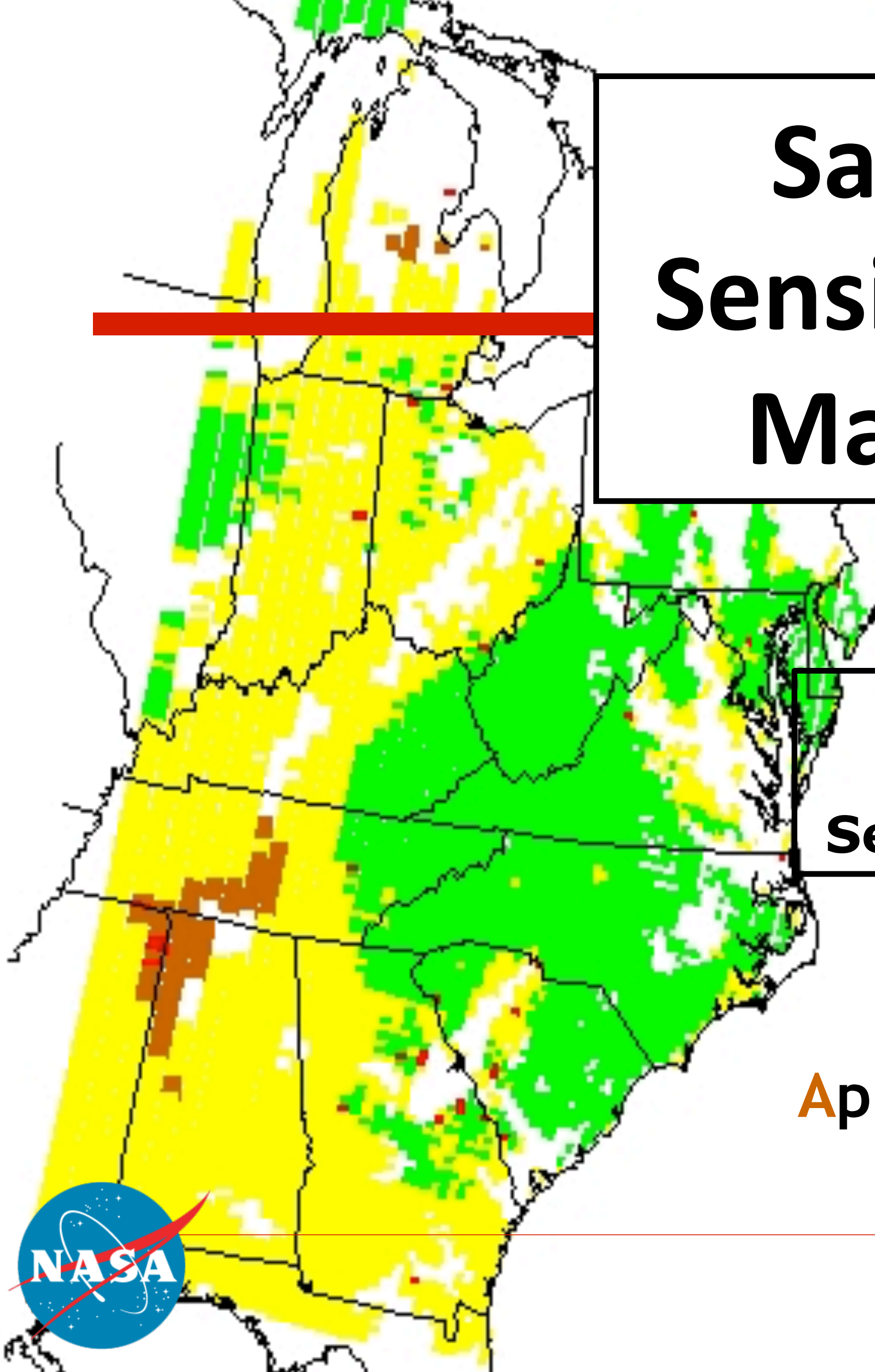


Satellite Remote Sensing of Particulate Matter Air Quality

Pawan Gupta

EPA Training

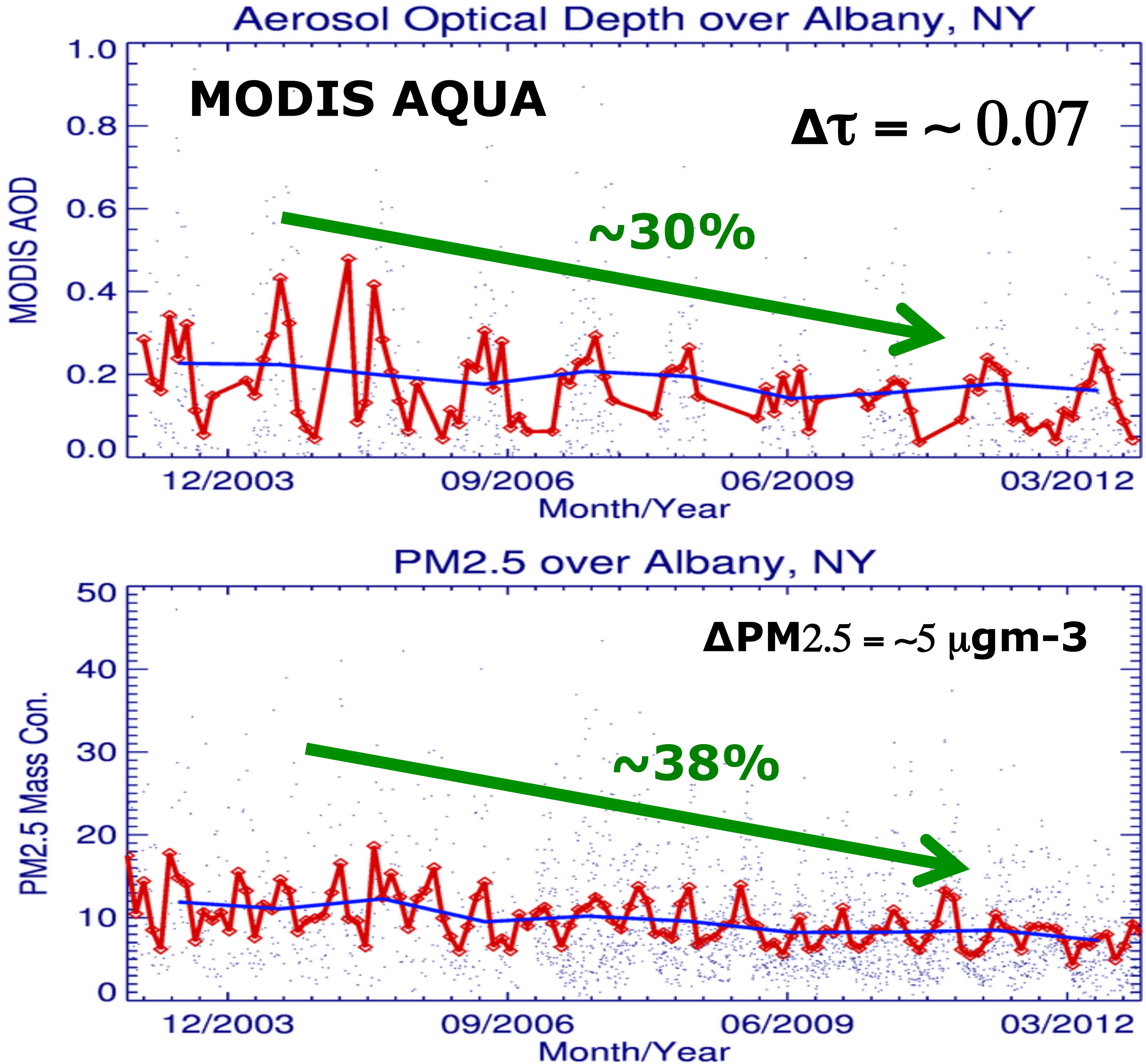
September 29 – October 1, 2014

ARSET

Applied Remote Sensing Education and Training

A project of NASA Applied Sciences

Aerosol Trend over Albany



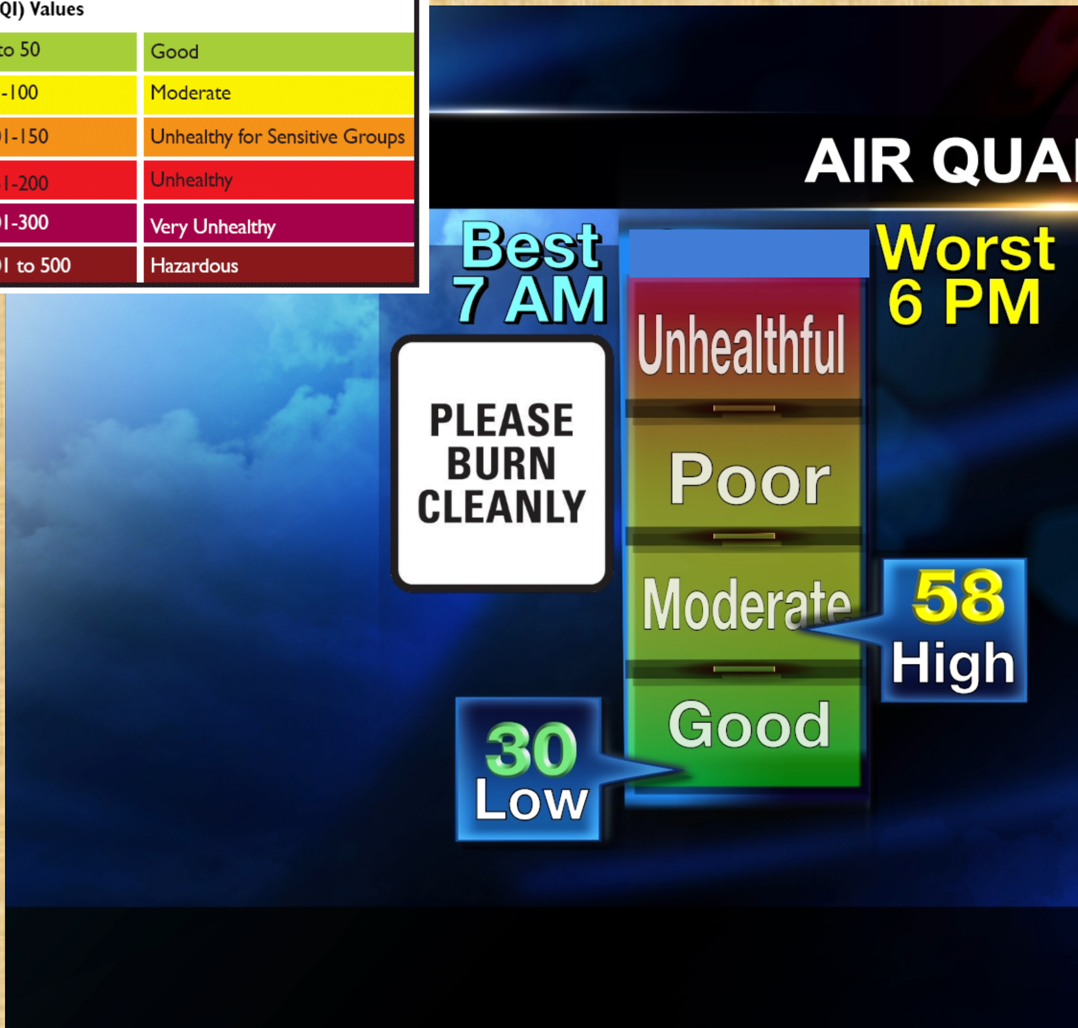
OBJECTIVE

Estimation of PM2.5 mass concentration at surface (μgm^{-3}) while utilizing satellite derived Aerosol Optical Depth (AOD – unit less quantity) at visible wavelength

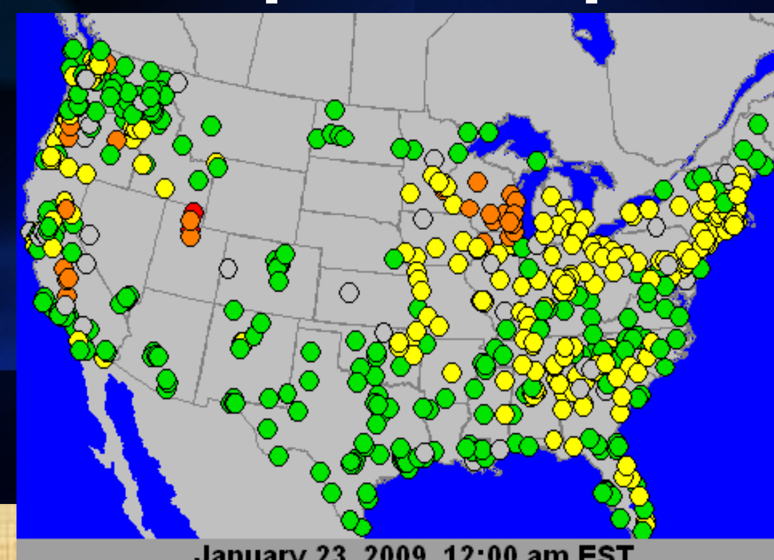
AIR QUALITY INDEX

Air Quality Index (AQI) Values	Levels of Health Concern
0 to 50	Good
51-100	Moderate
101-150	Unhealthy for Sensitive Groups
151-200	Unhealthy
201-300	Very Unhealthy
301 to 500	Hazardous

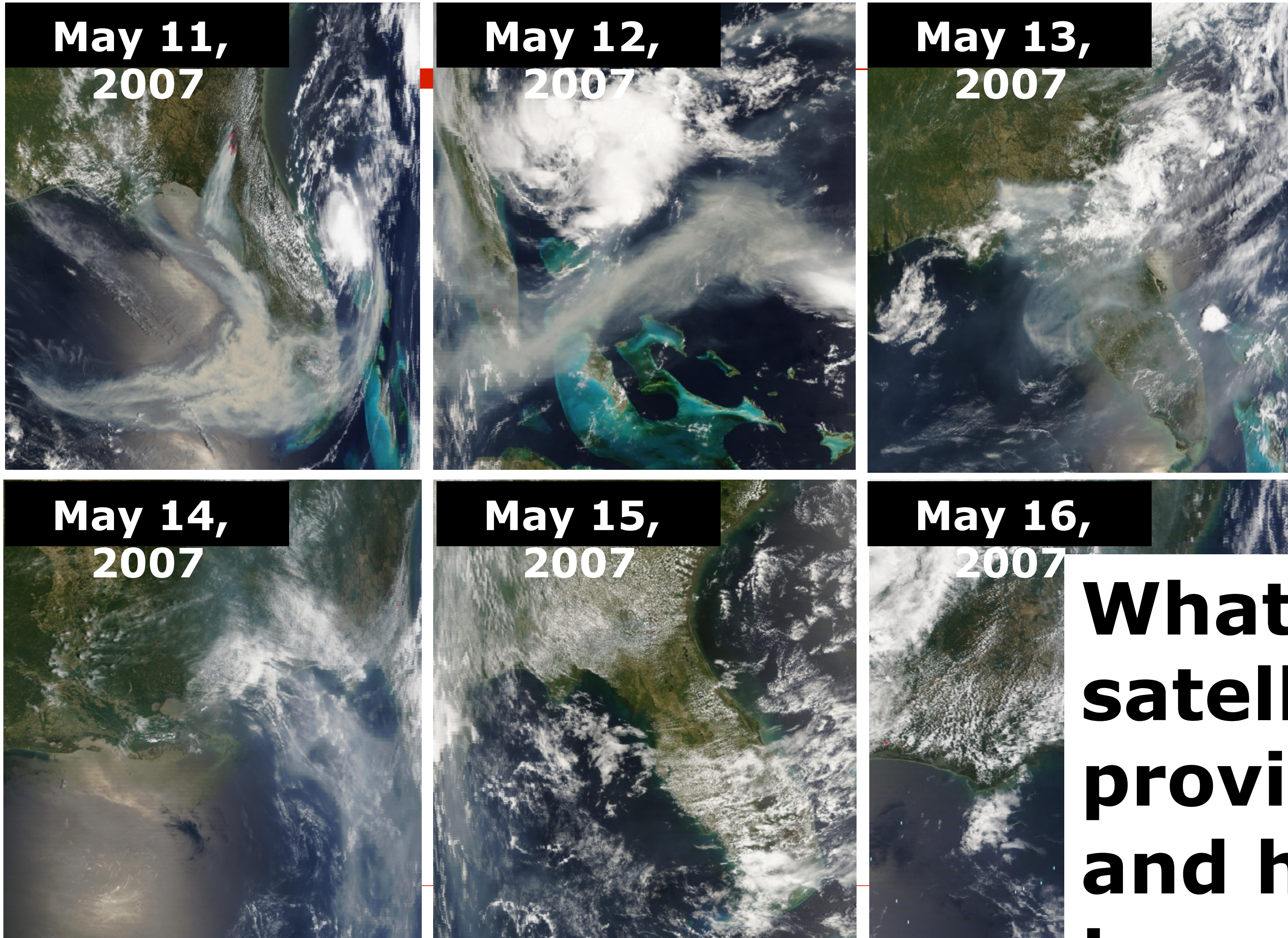
What are we looking for ? & Why ?



Spatial Gaps



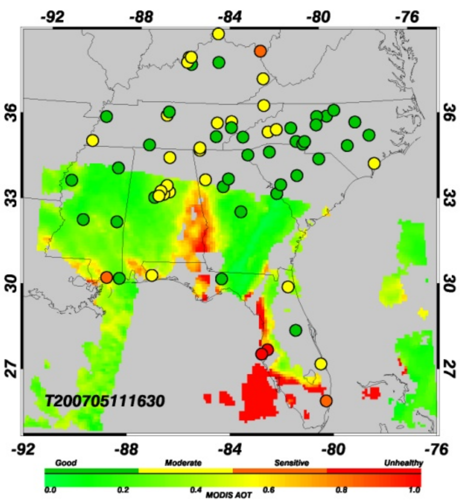
MODIS-Terra True Color Images



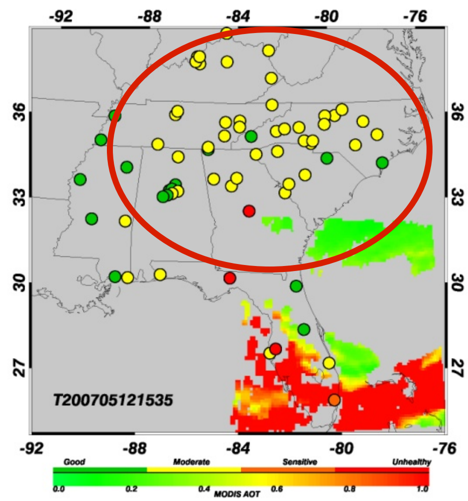
What satellite provides and how to get it?

MODIS-Terra Aerosol Optical Thickness

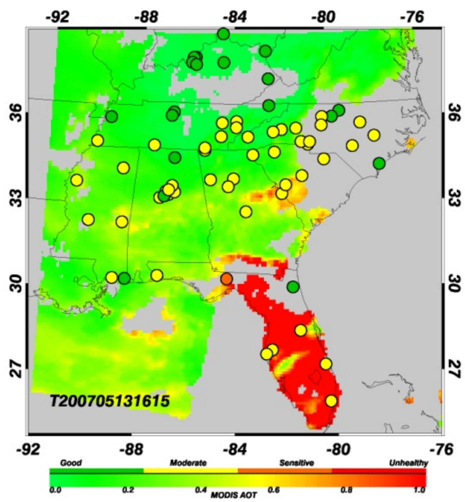
May 11, 2007



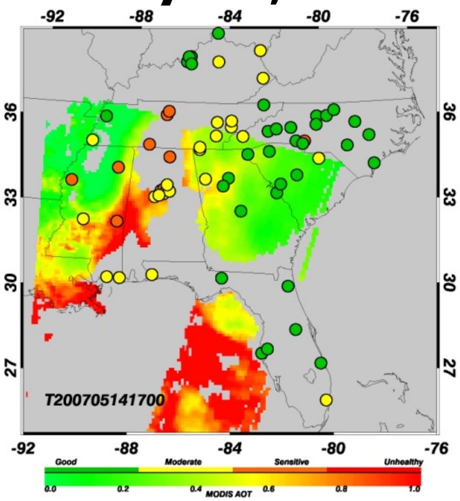
May 12, 2007



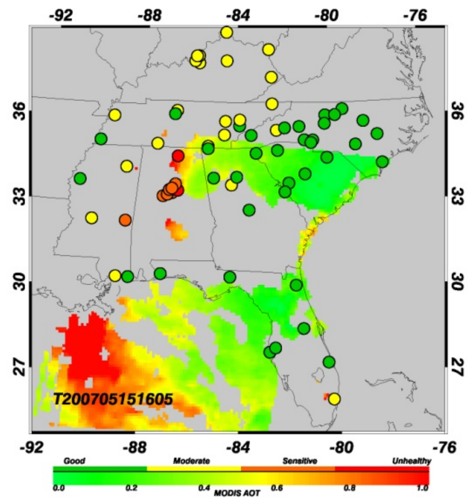
May 13, 2007



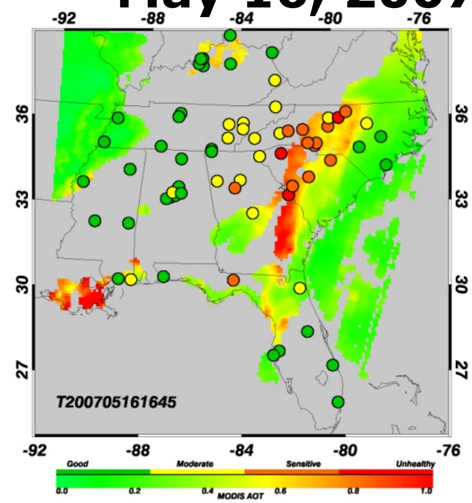
May 14, 2007



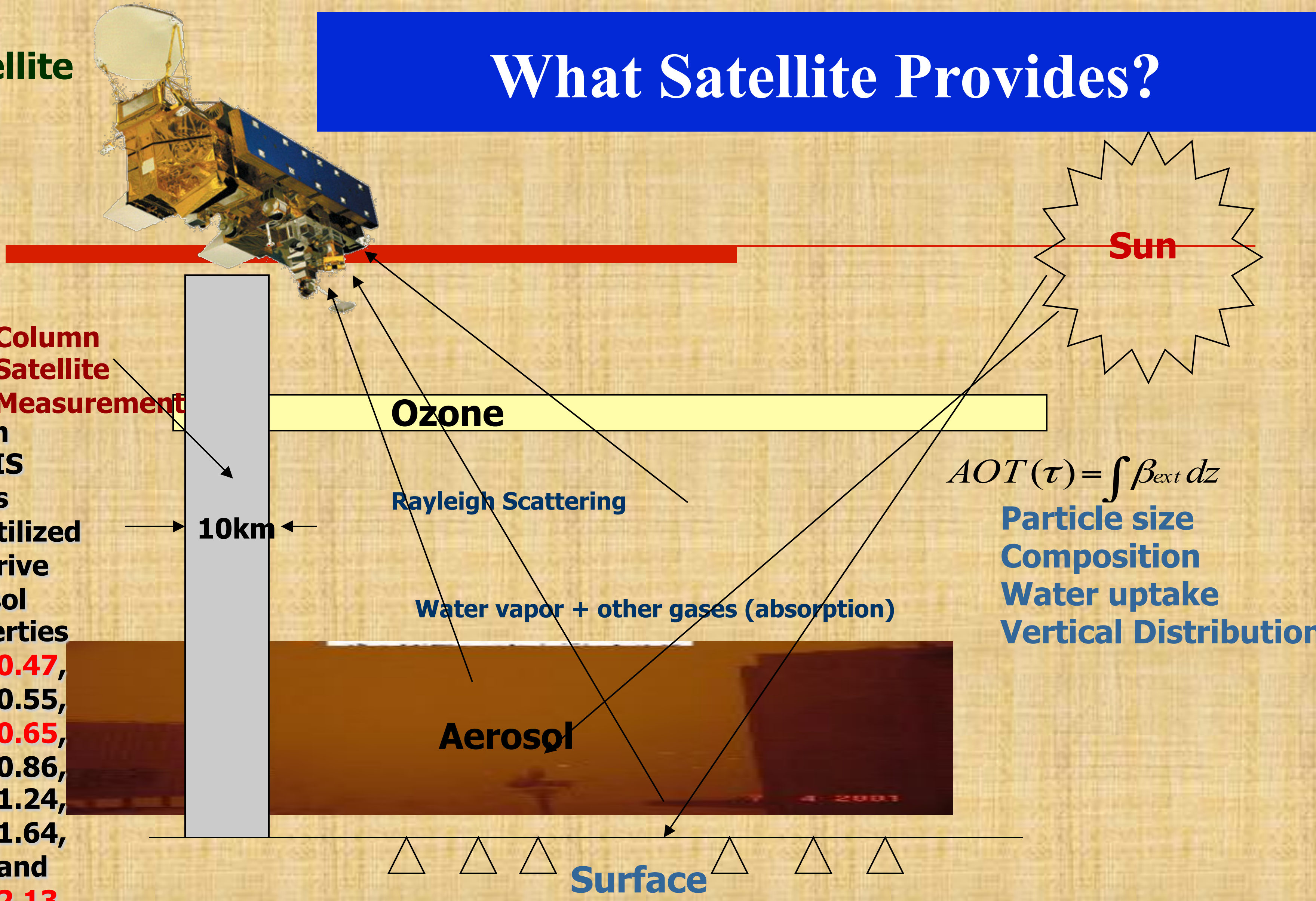
May 15, 2007



May 16, 2007



What Satellite Provides?



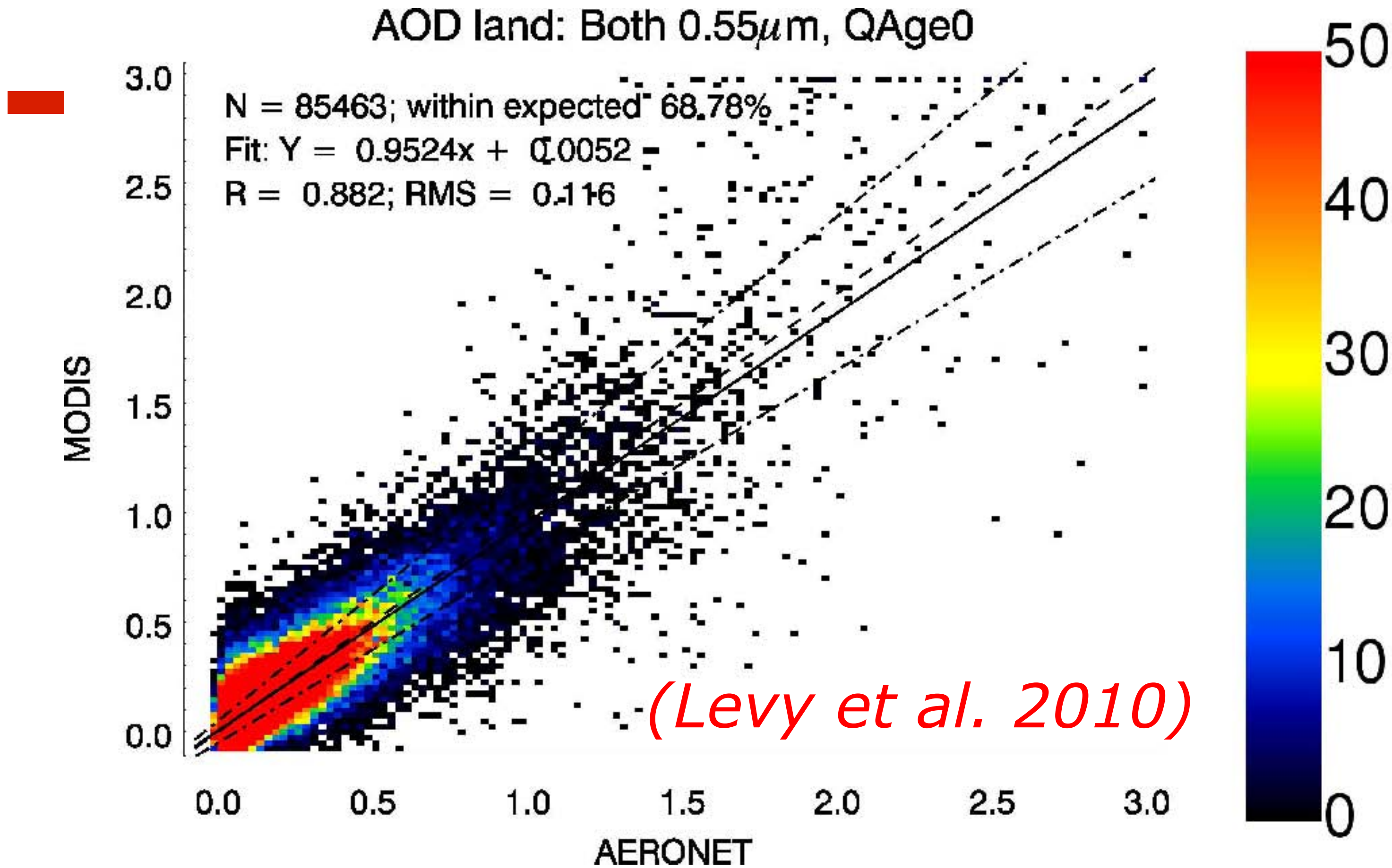
Seven MODIS bands are utilized to derive aerosol properties

0.47, 0.55, 0.65, 0.86, 1.24, 1.64, and 2.13 µm

10X10 km^2 Res.

Satellite retrieval issues - inversion (e.g. aerosol model, background).

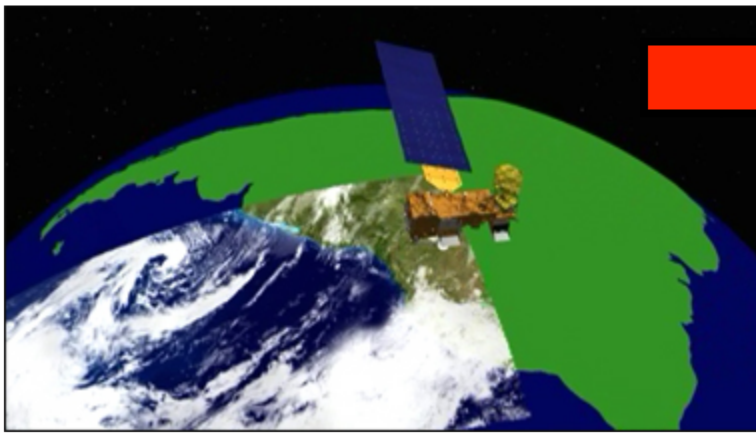
Data Quality – MODIS DT Product



Expected error: $\pm(0.05+0.15\tau)$

AOT to PM

Measurement Technique

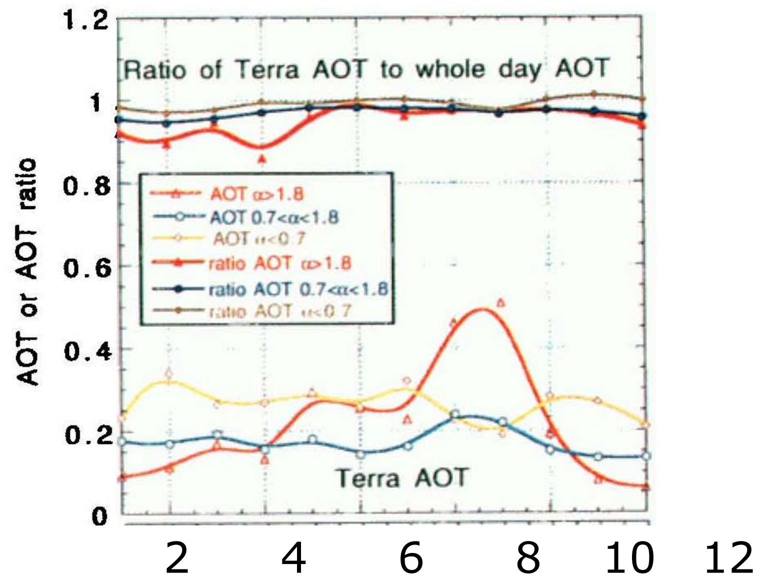


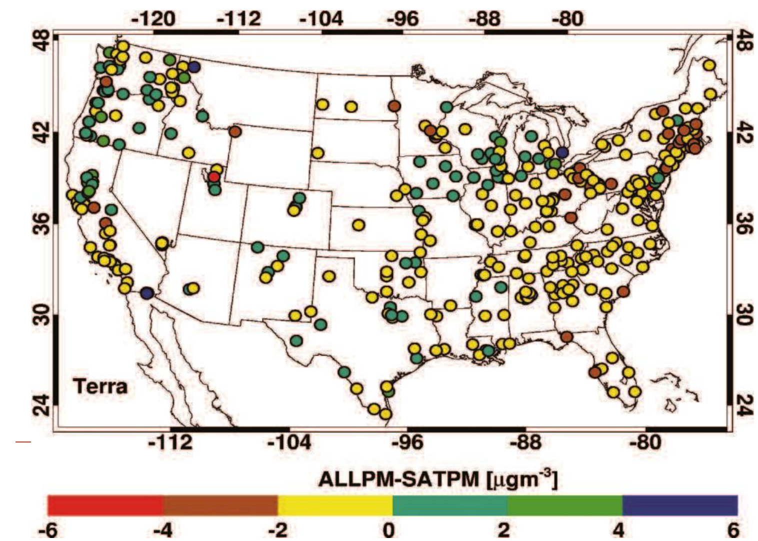
AOD – Column integrated value (top of the atmosphere to surface) - Optical measurement of aerosol loading – unit less. AOD is function of shape, size, type and number concentration of aerosols

PM2.5 – Mass per unit volume of aerosol particles less than 2.5 µm in aerodynamic diameter at surface (measurement height) level

Support for AOD-PM$_{2.5}$ Linkage

- Current satellite AOD is sensitive to PM$_{2.5}$ (Kahn et al. 1998)
- Polar-orbiting satellites can represent at least daytime average aerosol loadings (Kaufman et al., 2000)
- Missing data due to cloud cover appear random in general (Christopher and Gupta, 2010)





AOD – PM Relation

Top-of-Atmosphere

$$AOD(\lambda) = \int_0^{TOA} \beta_{ext,p}(\lambda, z)\,dz$$

surface

$$C = \frac{4\rho r_e}{3Q} \times \frac{f_{PBL}}{H_{PBL}} \times AOD$$

- ρ – particle density
- Q – extinction coefficient

Composition

- r_e – effective radius ⟹ **Size distribution**

- f_{PBL} – % AOD in PBL
- H_{PBL} – mixing height

Vertical profile

Simple Models from Early Days

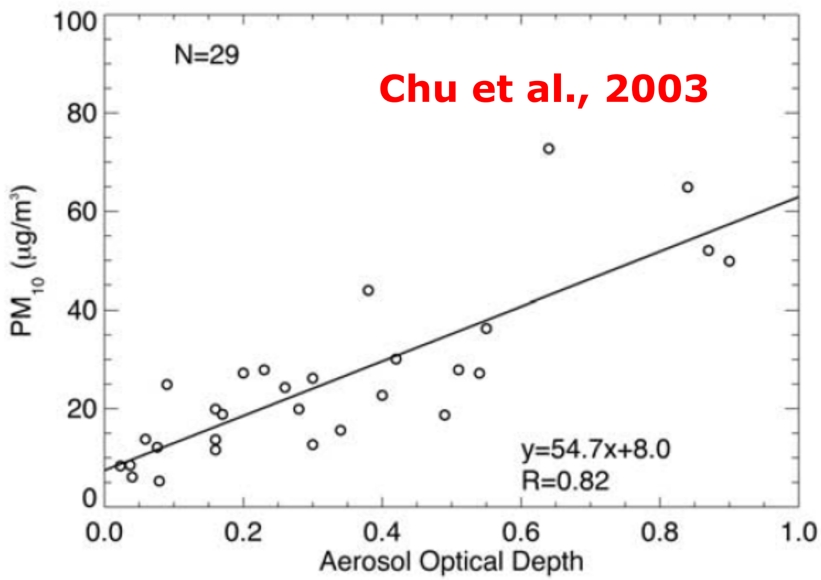
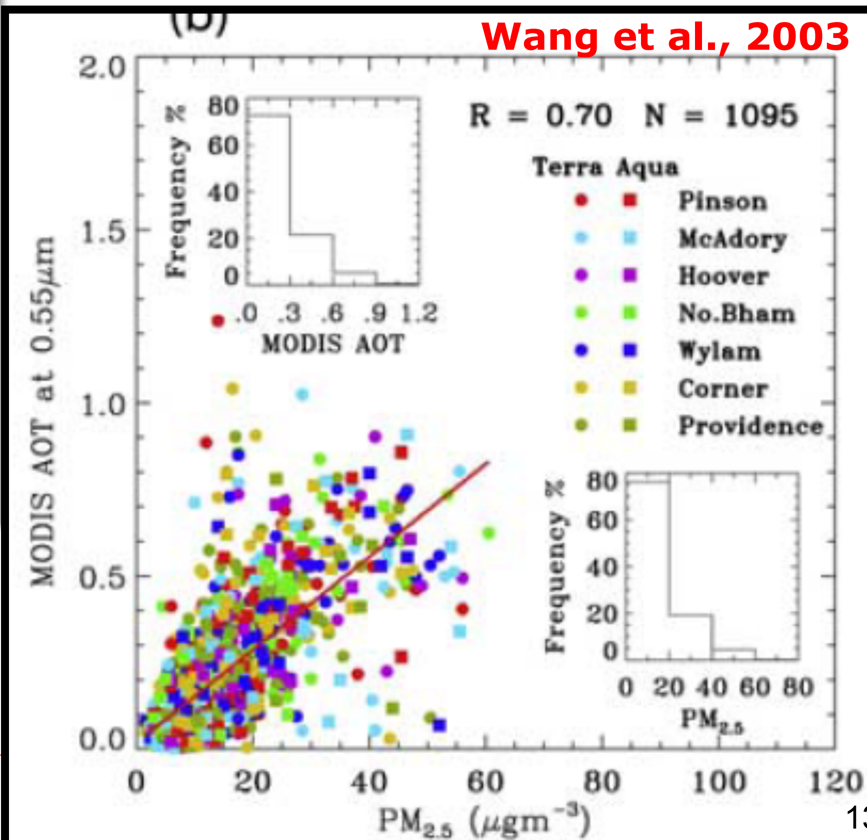
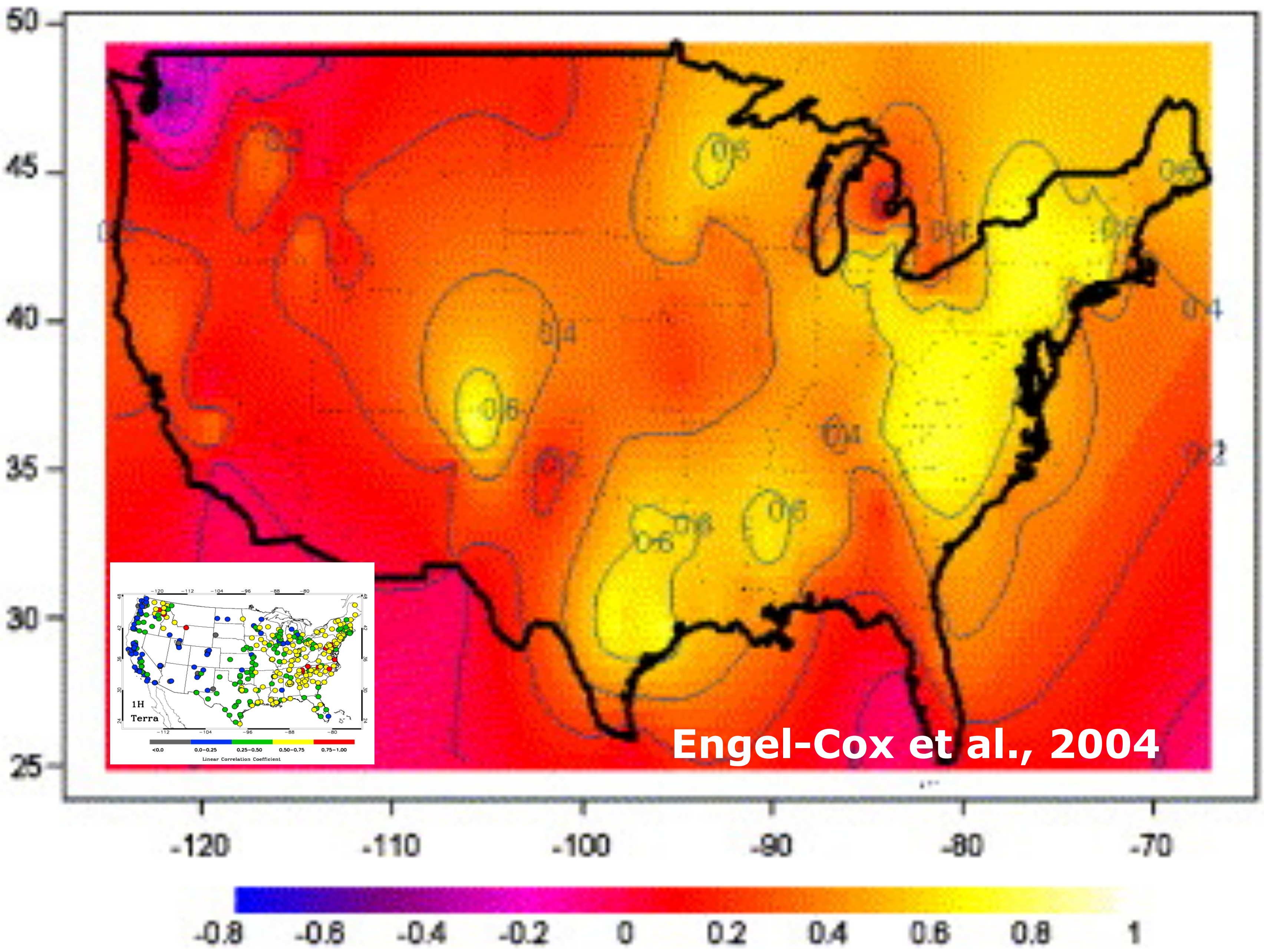


Figure 14. Relationship between 24-hour PM_{10} concentrations and daily averaged AERONET τ_a measurements from August to October 2000 in northern Italy.



AOT-PM2.5 Relationship

Correlations between AOD and PM2.5(hourly)



Questions to Ask: Issues

- ✓How accurate these estimations are ?
- ✓Is PM2.5-AOT relationship is always linear?
- ✓How does uncertainty in AOT retrieval impact estimation of air quality
- ✓Does this relationship changes in space and time?
- ✓Does this relationship changes with change in aerosol type?
- ✓How meteorology drive this relationship?
- ✓How about vertical distribution of aerosols in the atmosphere?

Assumption for Quantitative Analysis

When most particles are concentrated and well mixed in the boundary layer, satellite AOD contains a strong signal of ground-level particle concentrations.

Modeling the Association of AOD With $PM_{2.5}$

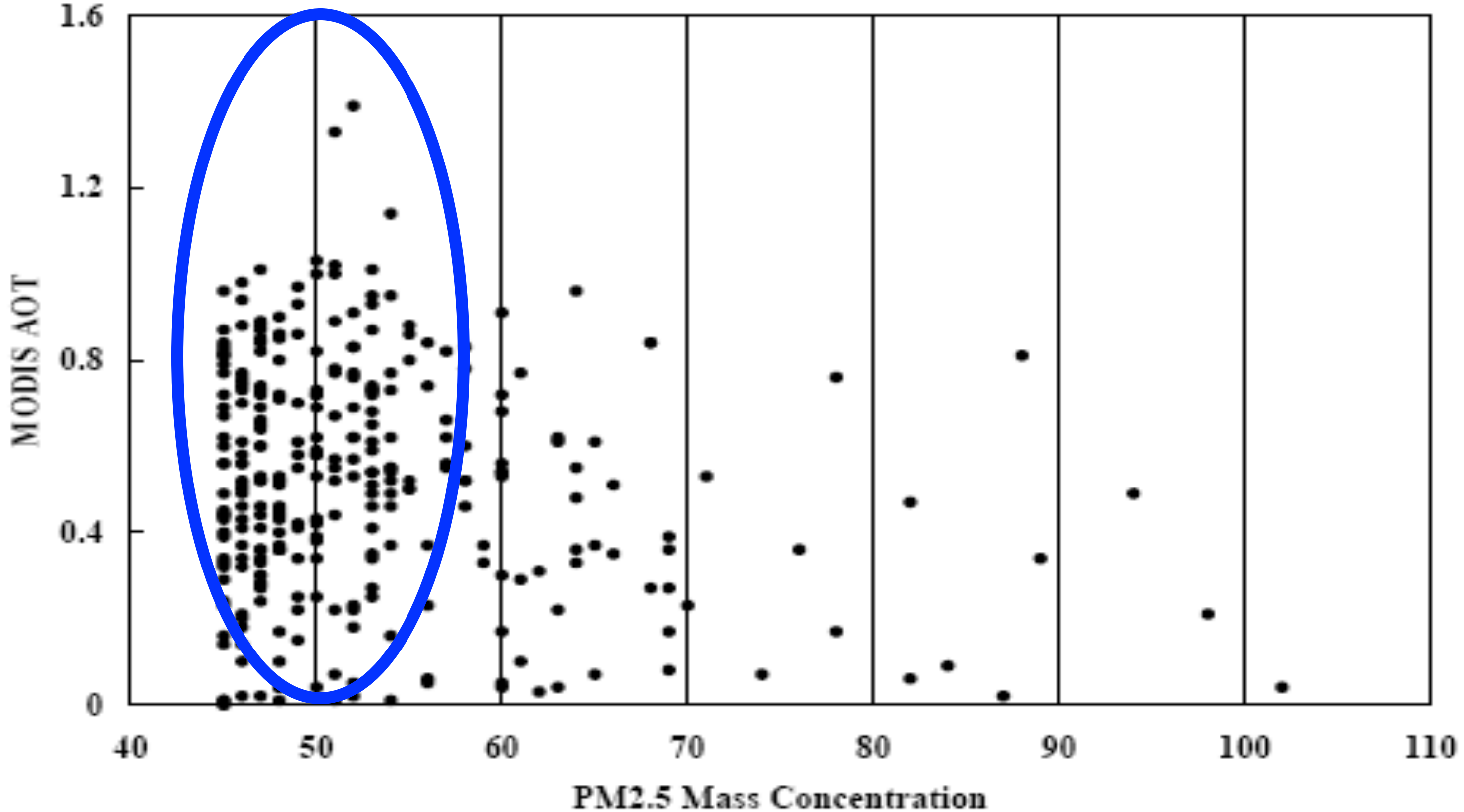
- The relationship between AOD and $PM_{2.5}$ depends on parameters hard to measure:
  - Vertical profile
  - Size distribution and composition
  - Diurnal variability
- We develop statistical models with variables to represent these parameters
  - Model simulated vertical profile
  - Meteorological & other surrogates
  - Average of multiple AOD measurements

No textbook solution!

Methods Developed So Far

- Statistical models
  - Correlation & simple linear regression
  - Multiple linear regression with effect modifiers
  - Linear mixed effects models
  - Geographically weighted regression
  - Generalized additive models
  - Hierarchical models combining the above
  - Bayesian models
  - Artificial neural network
- Data fusion models
  - Combining satellite data with model simulations
- Deterministic models
  - Improving model simulation with satellite data

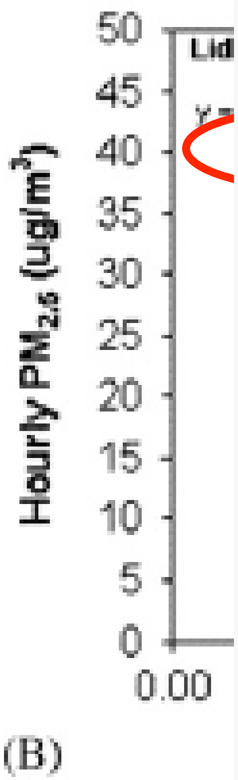
Limitation: Vertical Distribution of Aerosols

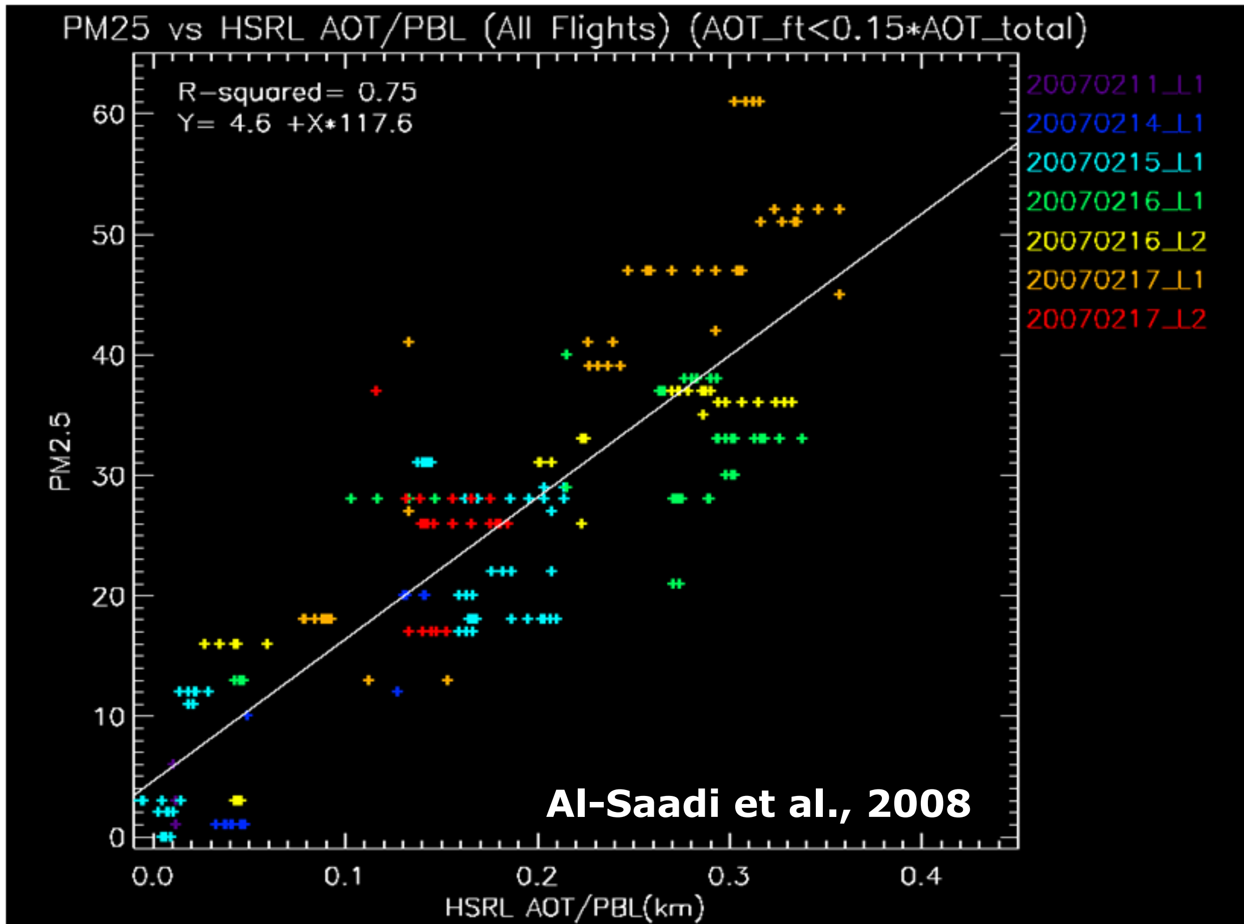


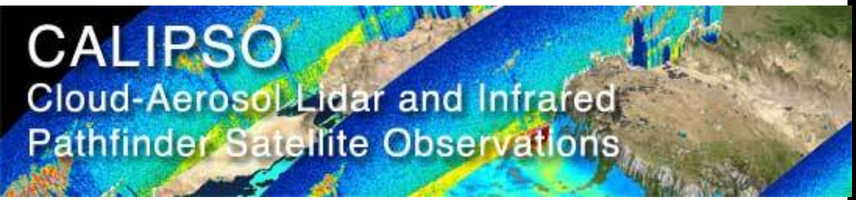
Vertical Distribution

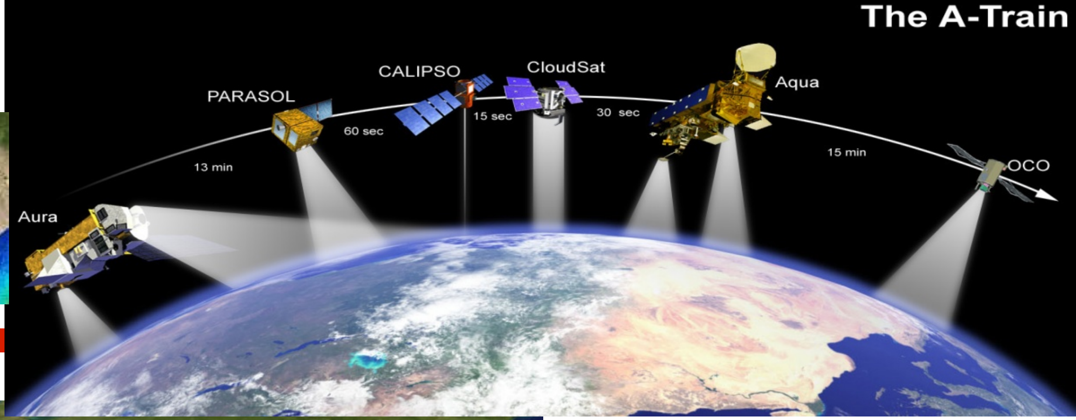
Correlation of Surface PM2.5 with HSRL AOD / PBL, All Flights

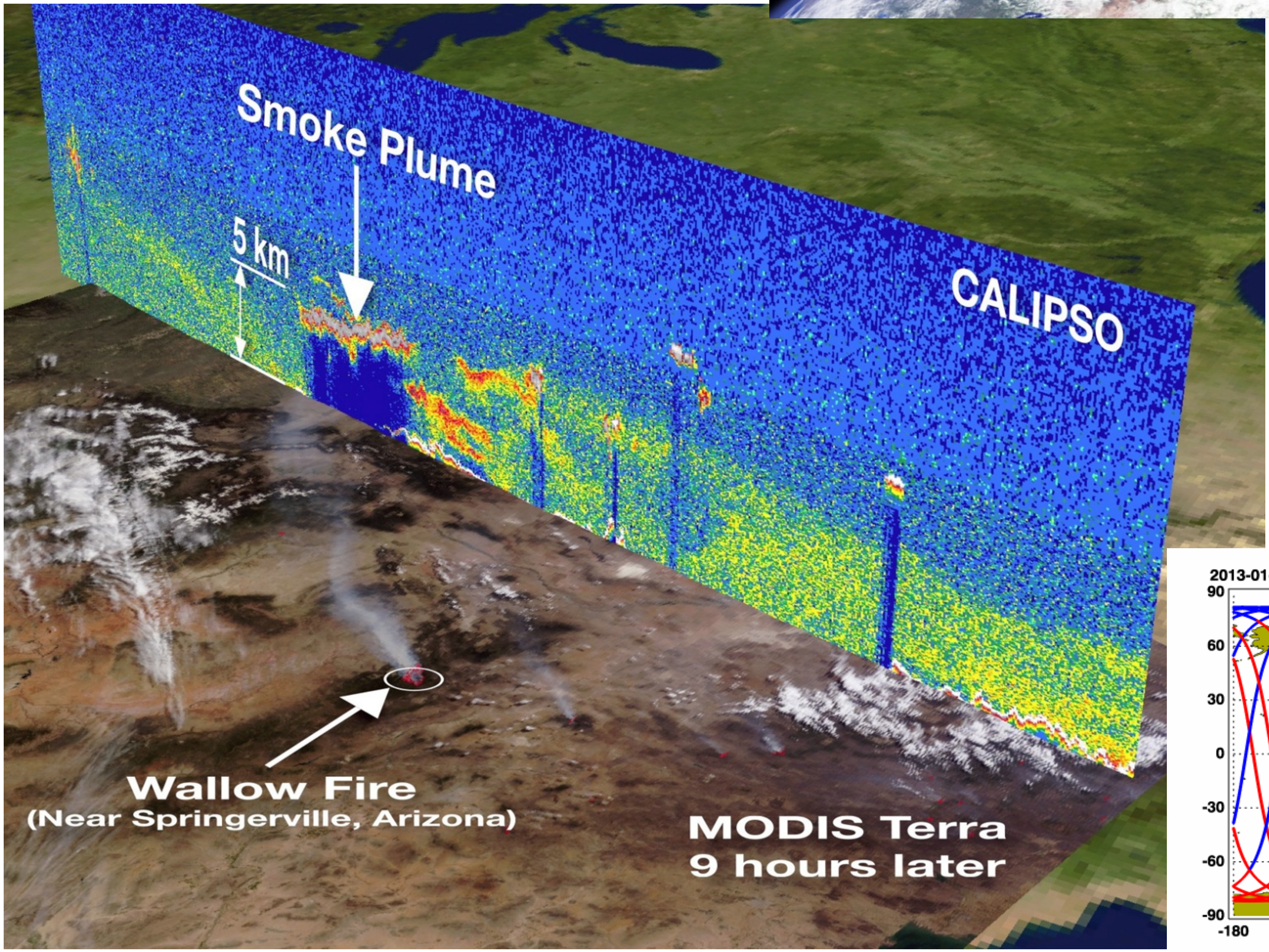
- Normalizing AOD with boundary layer height significantly improves correlation with $PM_{2.5}$ (R^2 increases from 0.36 to 0.75)
- With accurate estimates of PBL height, AOD can be good proxy for $PM_{2.5}$



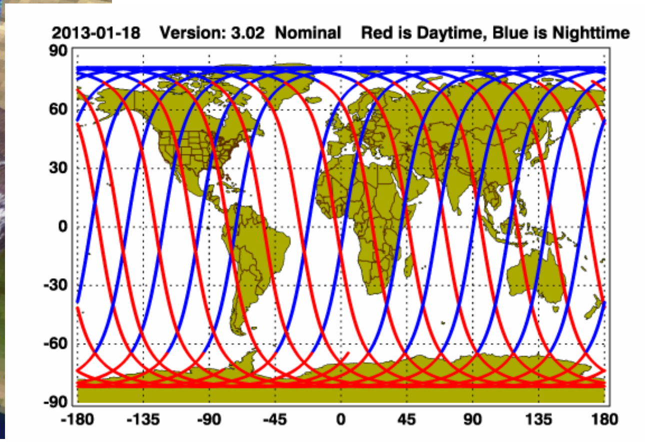






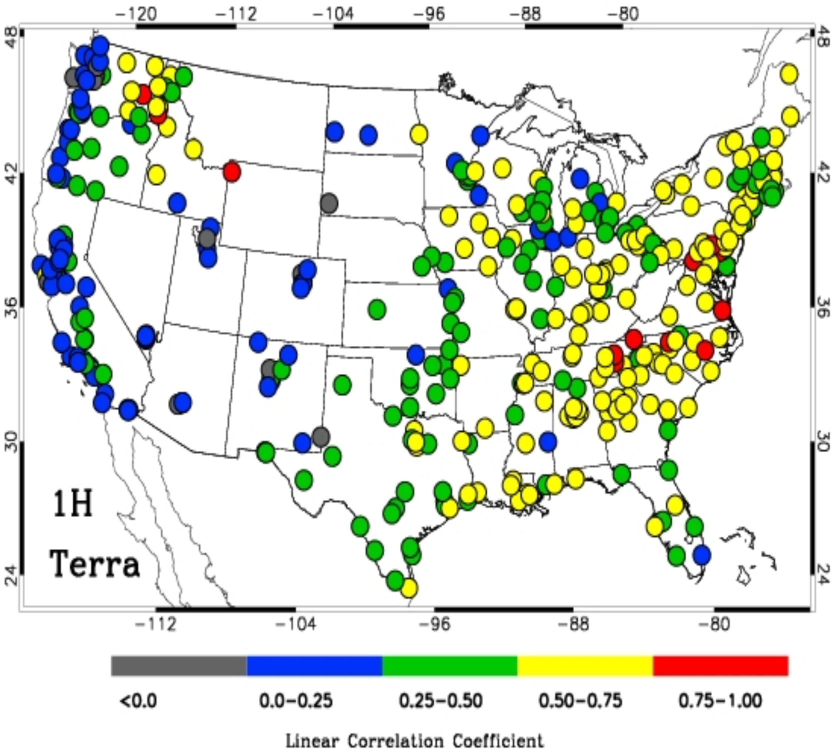


What Satellites can provide for vertical information? - CALIPSO

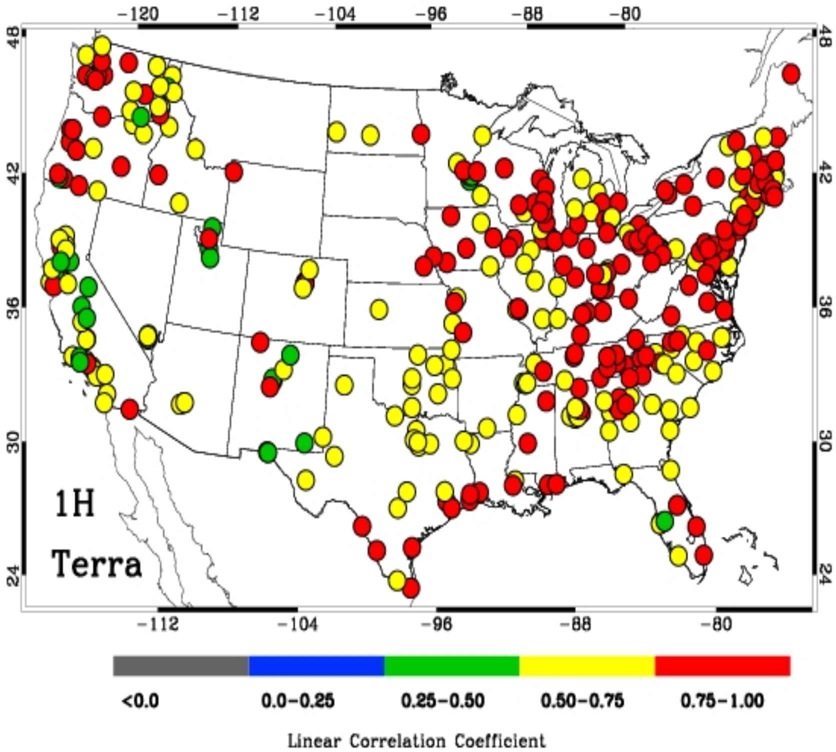


Advantages of using reanalysis meteorology along with satellite

Linear Correlation Coefficients



Observed vs Estimated (AOD only)

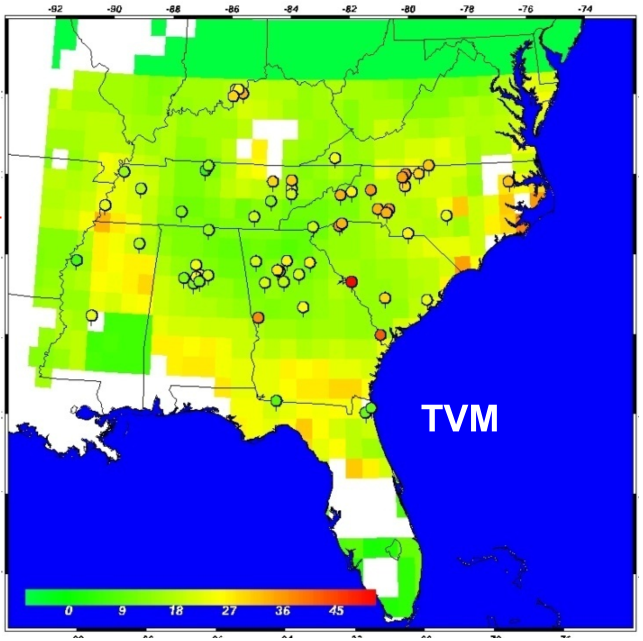


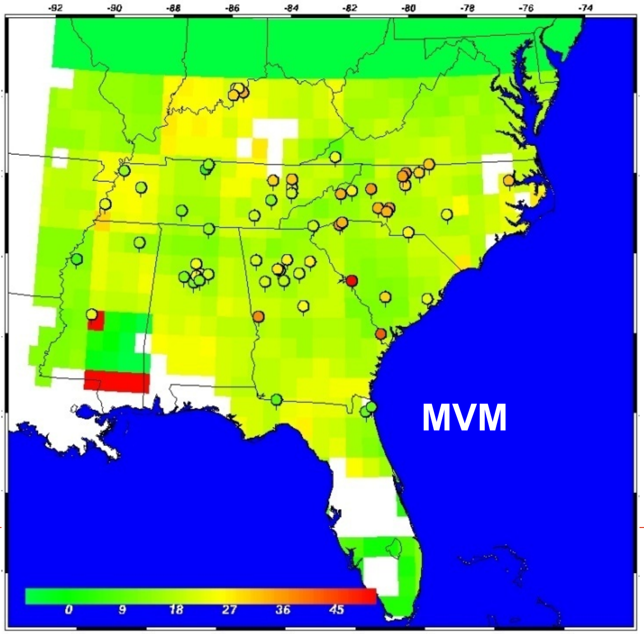
Observed vs Estimated (AOD + Meteorology)

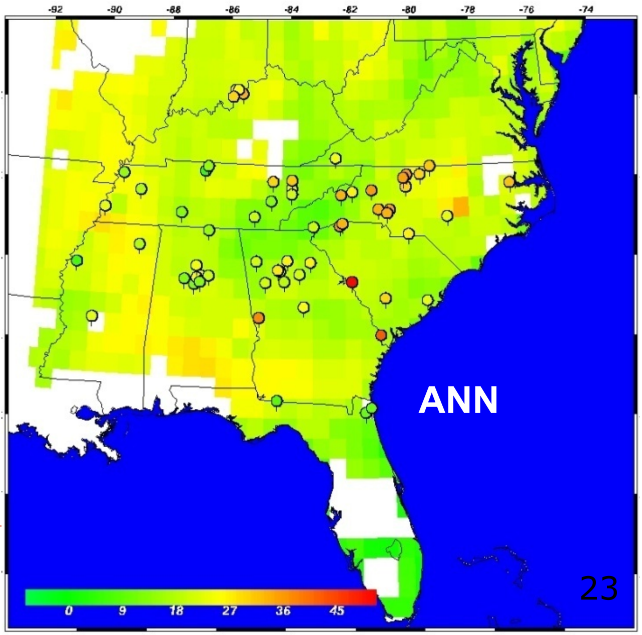
Gupta et al., 2009

Spatial Comparison

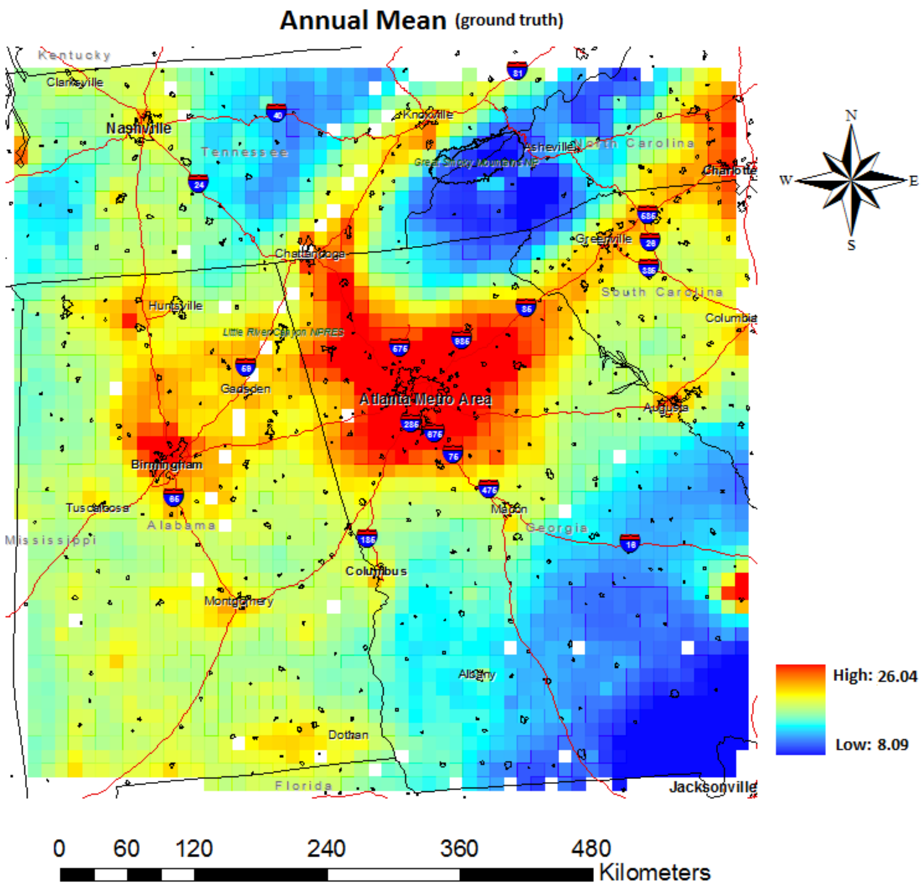
- **Satellite-derived PM2.5 fills the gap in surface measurements**
- **All three methods underestimate the higher PM2.5 concentrations.**

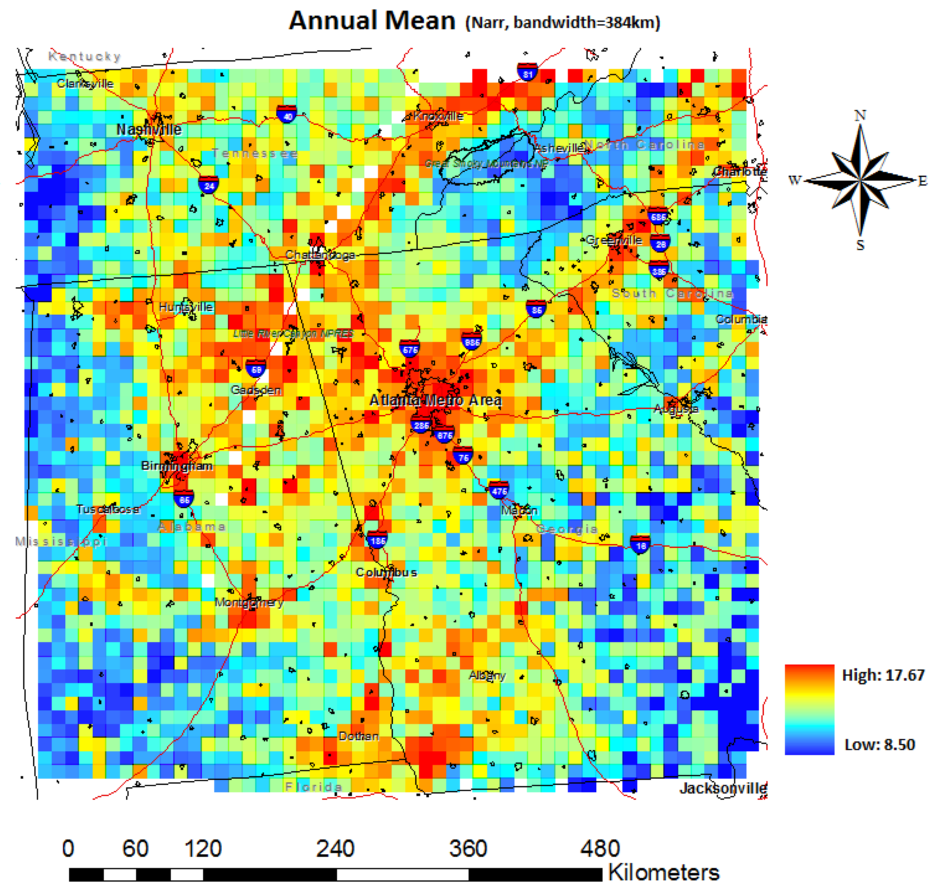






Comparison with CMAQ





Liu et al.,

General patterns agree, details differ

Scaling approach

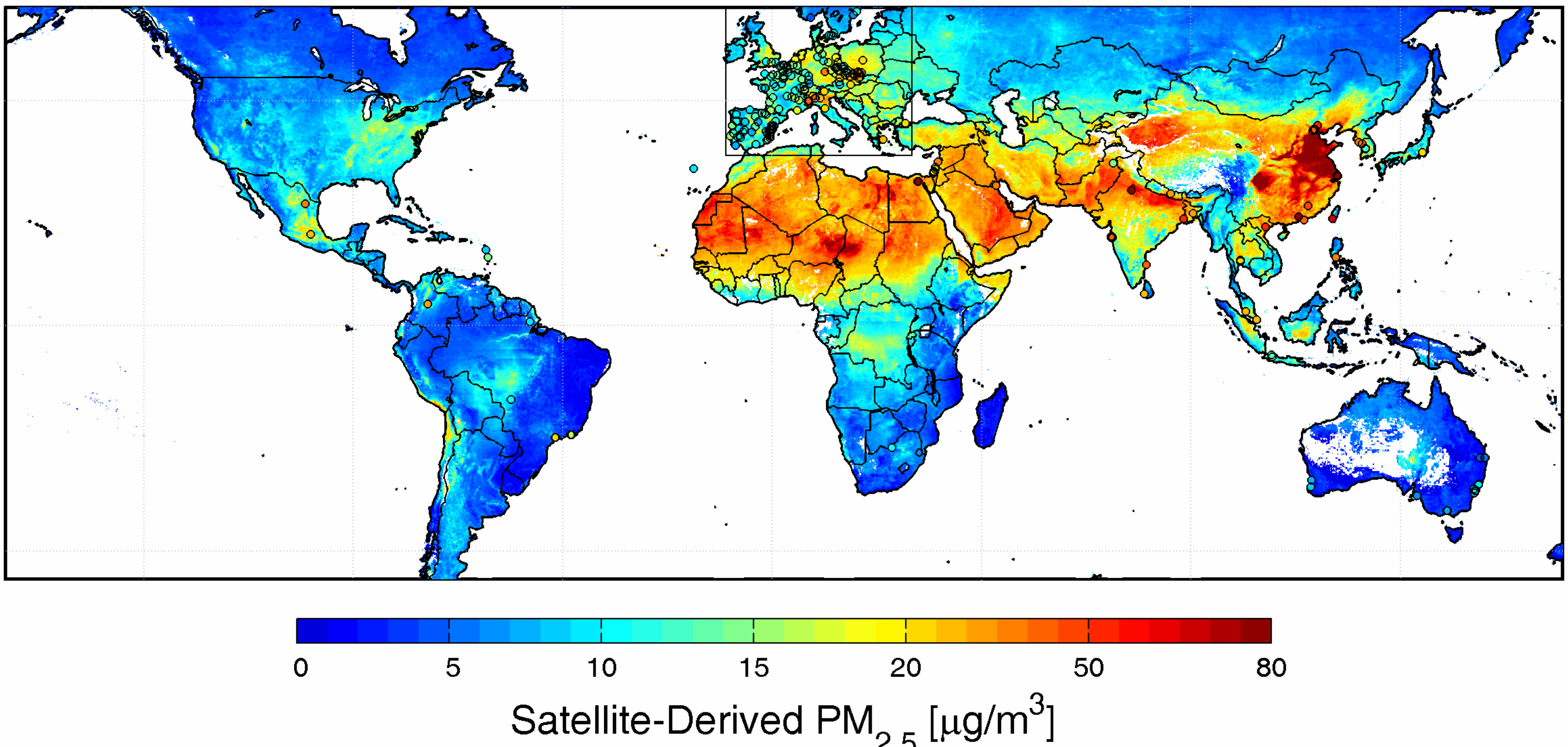
- Basic idea: let an atmospheric chemistry model decide the conversion from AOD to $PM_{2.5}$. Satellite AOD is used to calibrate the absolute value of the model-generated conversion ratio.

Satellite-derived $PM_{2.5}$ =

$$\left(\frac{PM_{2.5}}{AOD}\right)_{Model} \times \text{satellite AOD}$$

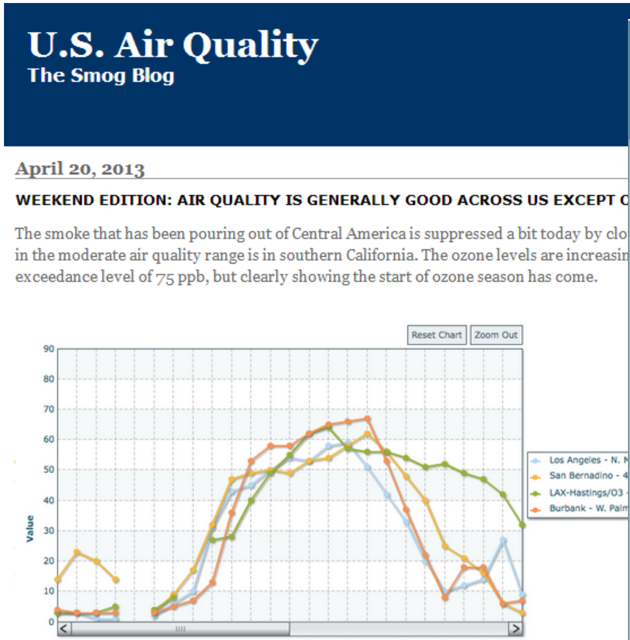
Liu et al., 2006,

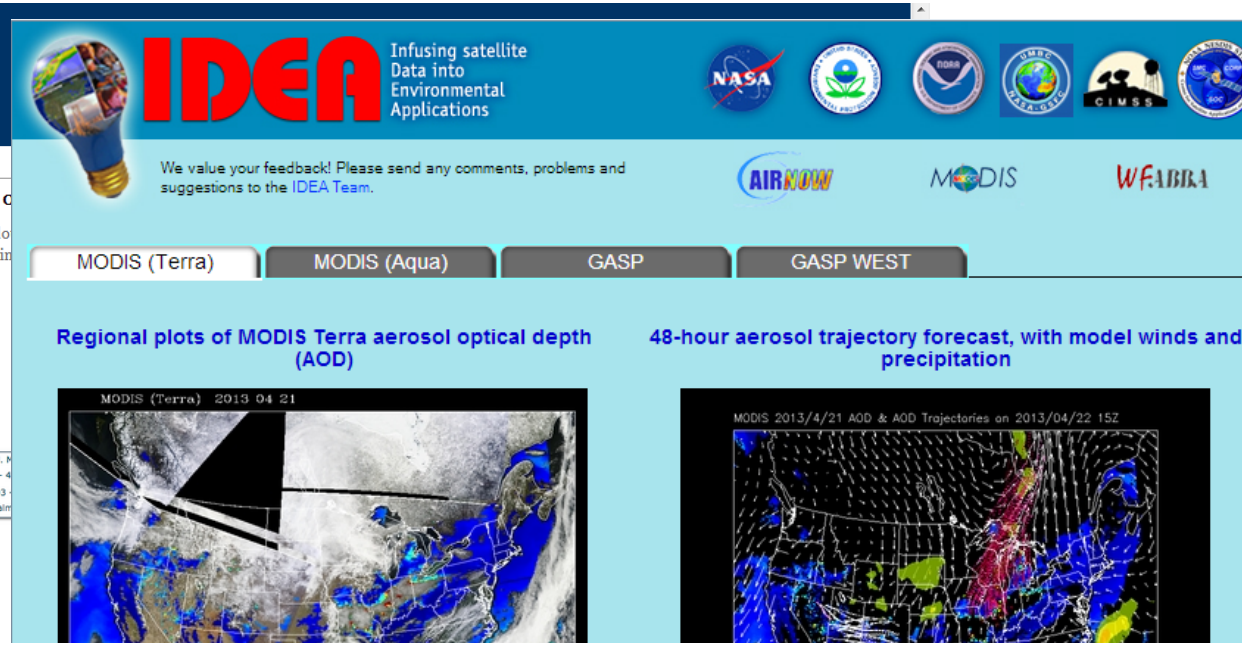
Scaling approach can be applied wherever there are satellite retrievals, but prediction accuracy can vary a lot.



(van Donkelaar et al. 2010)

Some online tools

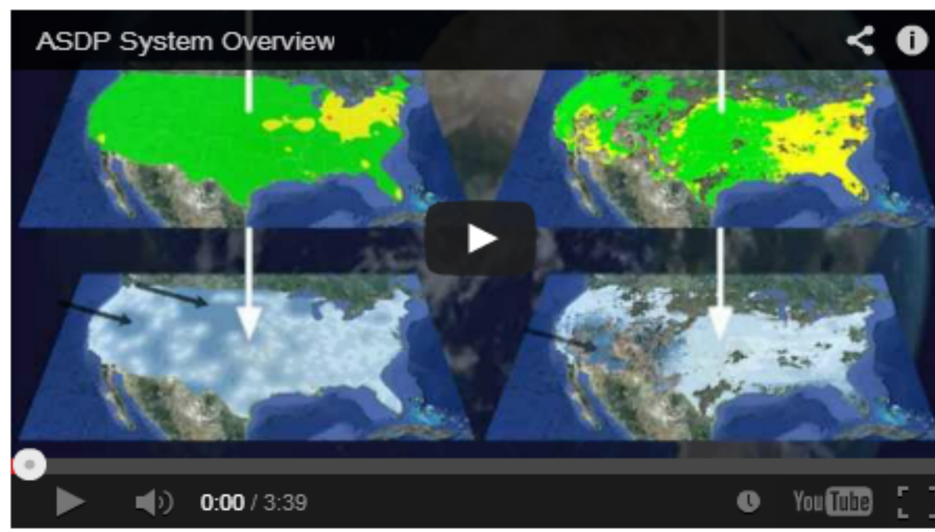




The AIRNow Satellite Data Processor (ASDP)

is a system under development that enables blending (or fusing) of surface $PM_{2.5}$ measurements and satellite-estimated $PM_{2.5}$ concentrations to provide additional air quality information to AIRNow in regions without existing surface air quality monitoring networks.

The ASDP system builds the capacity and framework necessary to implement satellite data as these data become available to the air quality community. This project is being funded by the NASA Applied Sciences Program.



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2009 CRITICAL REVIEW

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S.A. Christopher

Remote Sensing of Particulate Pollution
from Space: Ha
Promised Land

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Department of Physics and the Joint Center for Earth Systems Te... th Sciences
and Technology Center, University of Maryland, Balti...

Sundar A. Ch...

The use of the AOD as a measure for mass concentration has skill in some regions but less in others and does not provide a uniform way to measure aerosols across the United States. We discussed in Table 4 the range of mea-

dards (NAAQS).[142] The 39-yr history of those standards parallels the time period that satellite meteorology and observations have developed and yet, to date, no satellite measurements have been used to quantitatively address the NAAQS. From the review conducted here, only one congres-

IMPLICATIONS

Satellite measurements are going to be an integral part of the Global Earth Observing System of Systems. Satellite measurements by themselves have a role in air quality studies but cannot stand alone as an observing system. Data assimilation of satellite and ground-based measurements into forecast models has synergy that aids all of these air quality tools.

EPA has taken a satellite observations role for itself in the Exceptional Events Rule.[144] If a region can show conclusively that they are being impacted by an event (a fire, a dust storm, etc.) that is outside of their jurisdiction to regulate, the event can be flagged as a nonexceedance event. This provides a significant motivation for regional

ellite data possible in significant exceedances only. Applications such as event identification, transport, and atmospheric composition determination are strengths of satellite measurements. Where high precision is required (compliance monitoring, the "but for" test, and quantitative measurement of visibility effects on Class I areas), satellite data are presently of limited utility.

Although the desire for the use of satellite data for air quality purposes is widely stated, the reality is that many of the measurements have not yet met the promise that they can be operationally used for today's air quality monitoring requirements. Precision in measuring AOD is

Suggested Reading